Effect of Reservoir pH on a Novel Stimuli-Responsive/Rheoreversible Hydraulic Fracturing Fluid

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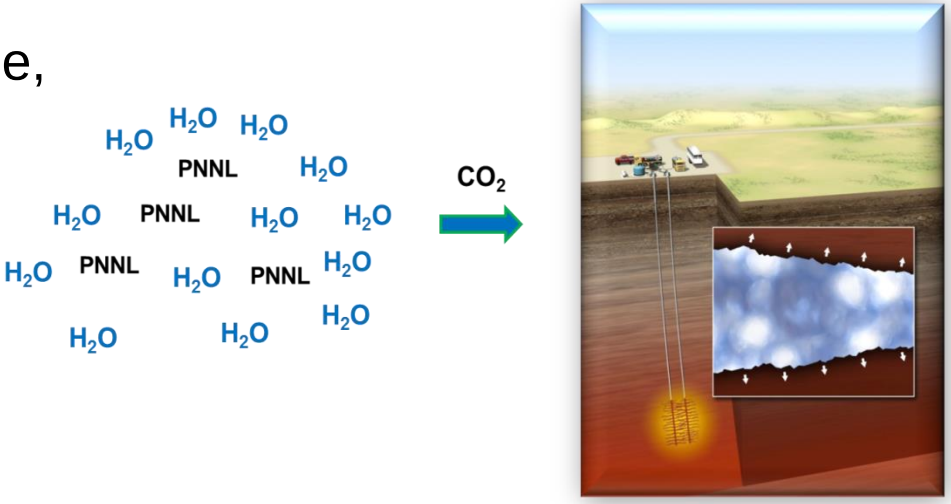
PNNL Rheoreversible Fracturing Fluid

- Consist of a stimuli-responsive fracturing fluid that can mediate a chemically-activated expansion in confined environments
- Provides a controllable increase of hydraulic stress to aid in fracturing processes, i.e., it expands where we want it to expand
- Provides *in situ* control of the rheological properties of the fracturing fluid
- Chemical stimulus is readily available, CO_2 (key process infrastructure is available, e.g., for EOR)



- Recyclable due to rheoreversibility (e.g., liquid to gel and gel to liquid)
- Nontoxic and inexpensive

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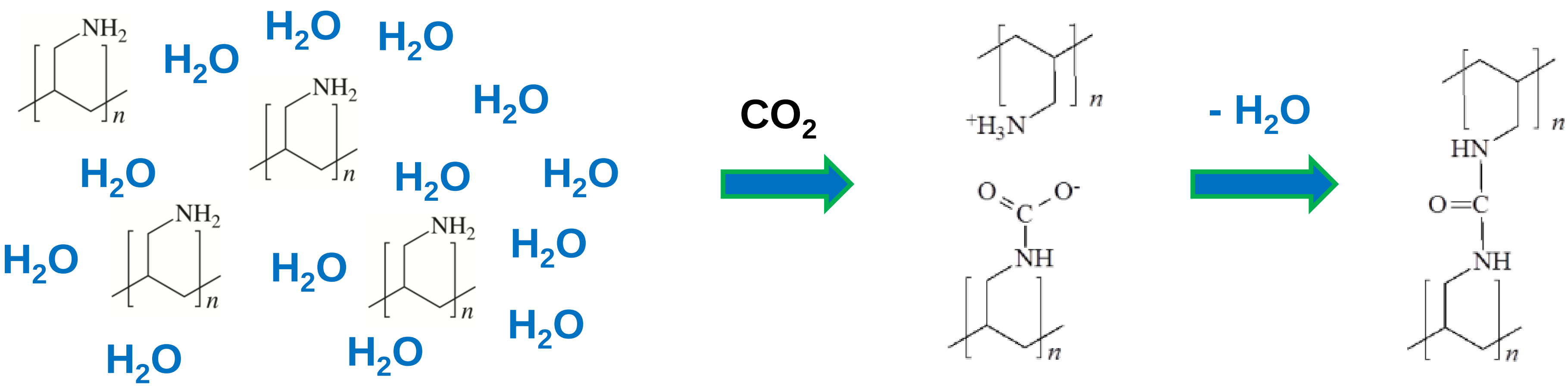
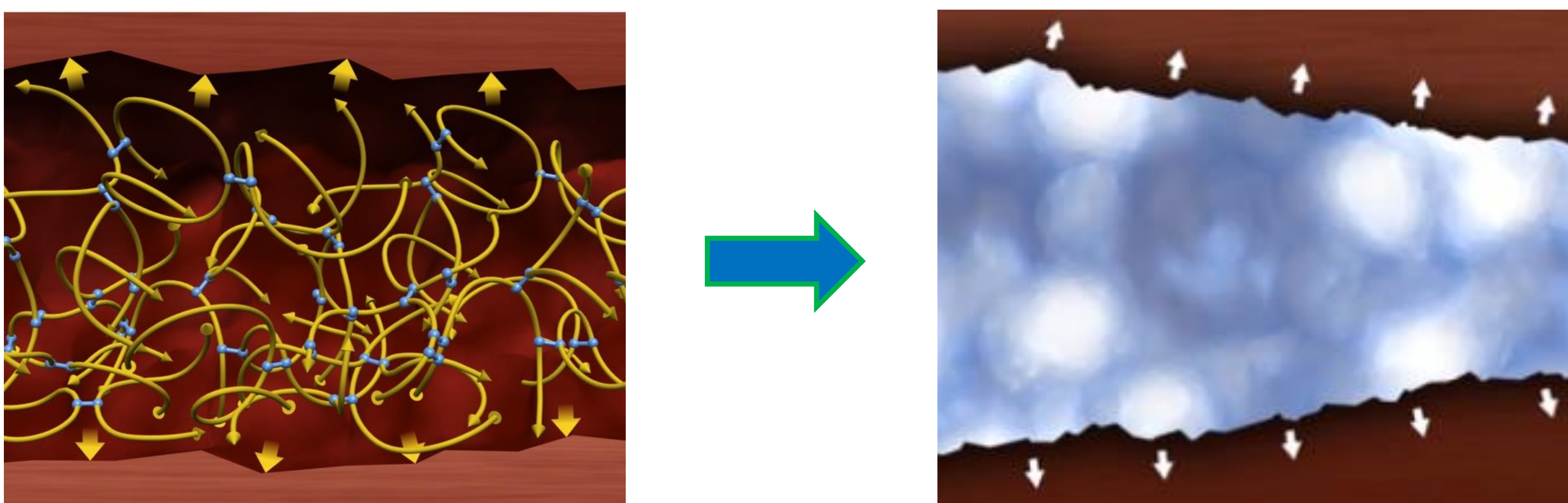
PNNL Technology

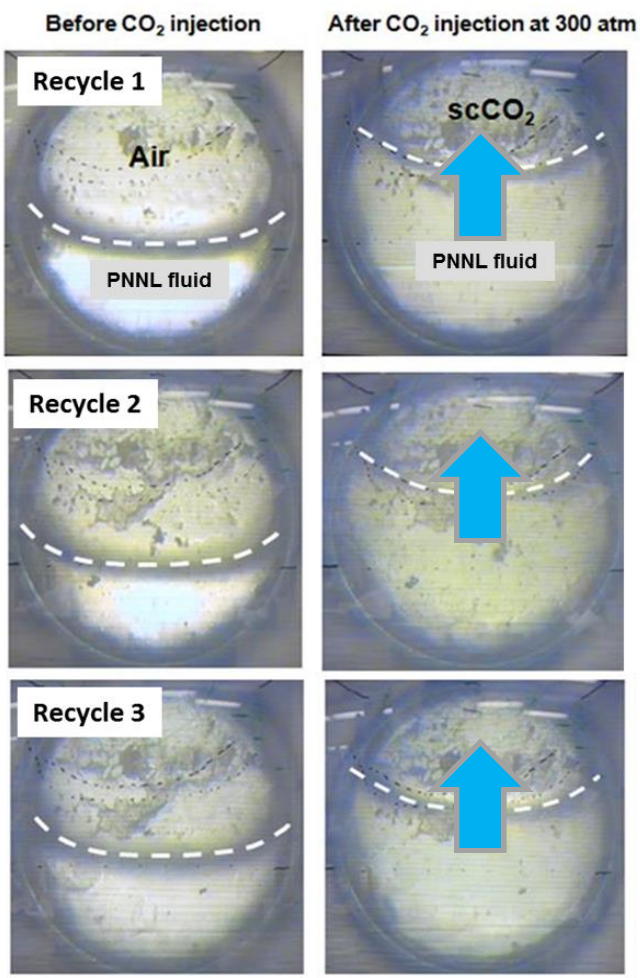


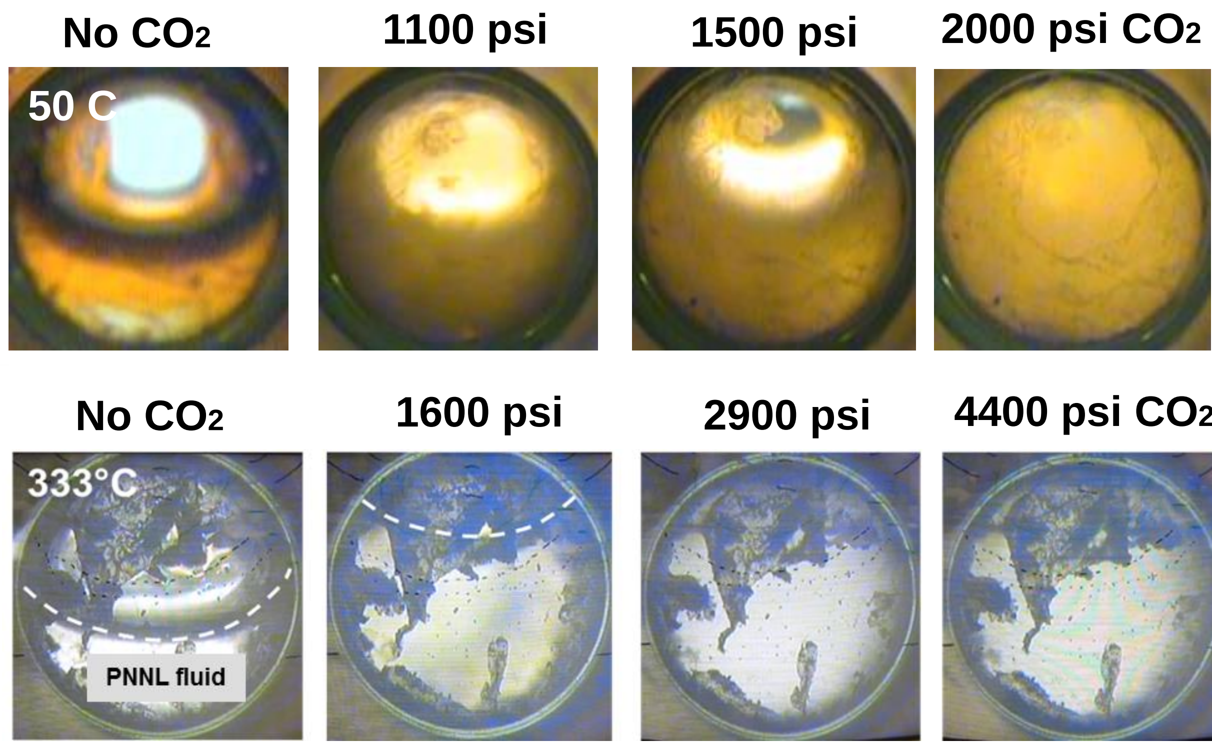


Impact on EGS and Tight Oil Recovery

- Will significantly **enhance permeability at effective stress *orders of magnitude* lower** than current technology
- Will **bring costs down significantly** in terms of number of stimulation stages, pumping costs and infrastructure
- Will **save a significant amount of water** during stimulation and consequently dramatically **reduce the volumes of wastewater** to be treated and disposed of
- Will considerably reduce environmental concerns, **single-component with high thermal stability and non-toxic**
- Apply the tunable rheological properties (e.g. viscosity) to **aid to the oil migration** to the surface
- **FLEXIBLE:** It can be potentially used in nearly ALL reservoirs

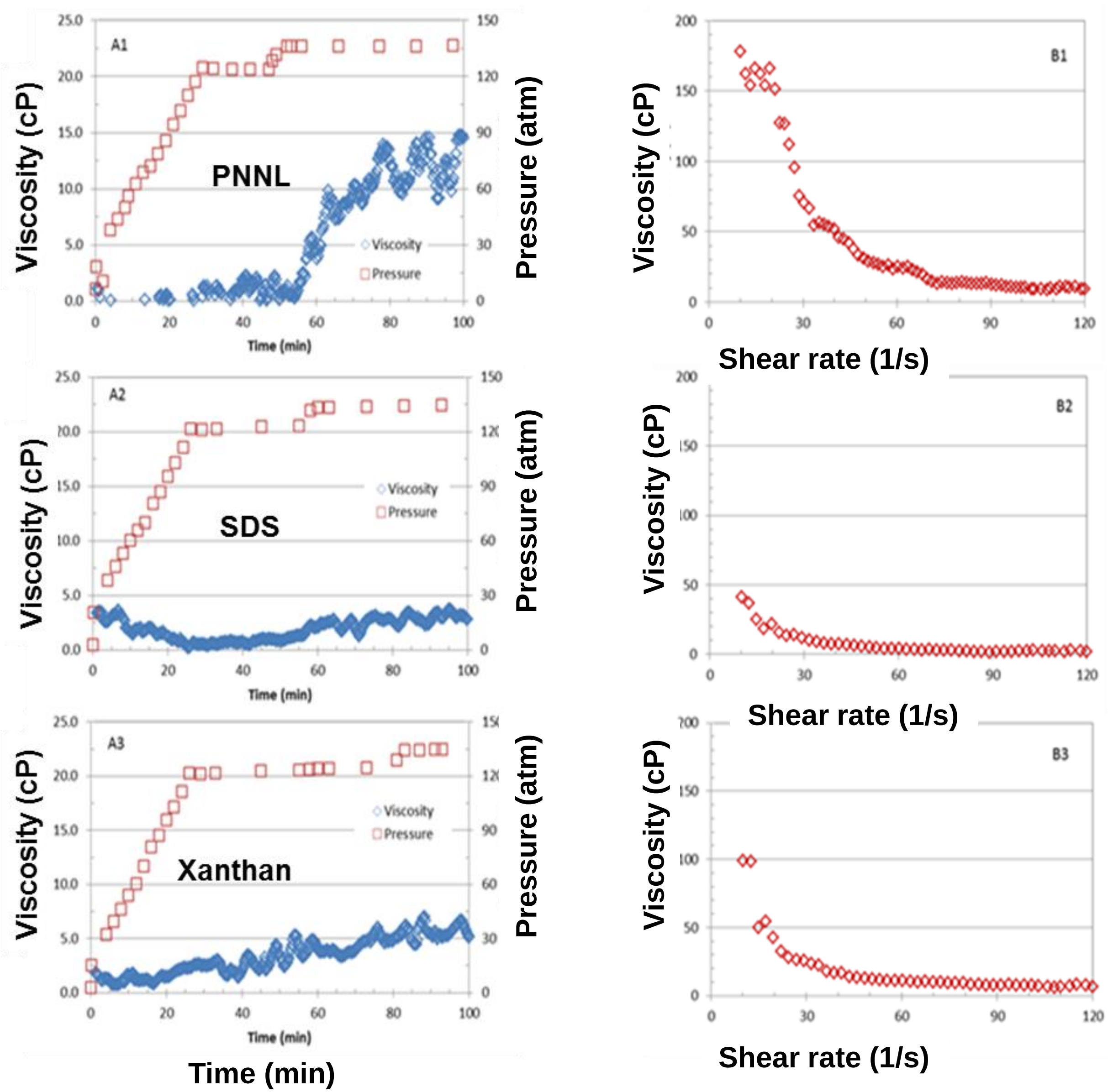
Remarkable Reversible Volume Expansion at Reservoir P/T





- Volume expansions of **up to 2.5 X** with an associated increase in fluid viscosity at a range of reservoir P & T conditions (196–402 ºC and 130–350 atm).
- 1 wt% aqueous PNNL fluid component
- PNNL fluid component stable at T as high as 400 ºC

Dramatic Viscosity Increase at Reservoir P/T



- **15X** viscosity increases at 130 atm and 190 ºC
- Shear-thinning properties of critical importance to support propagation and proppant transport into the reservoir during pumping (high shear rates).
- 1 wt% PNNL fluid component

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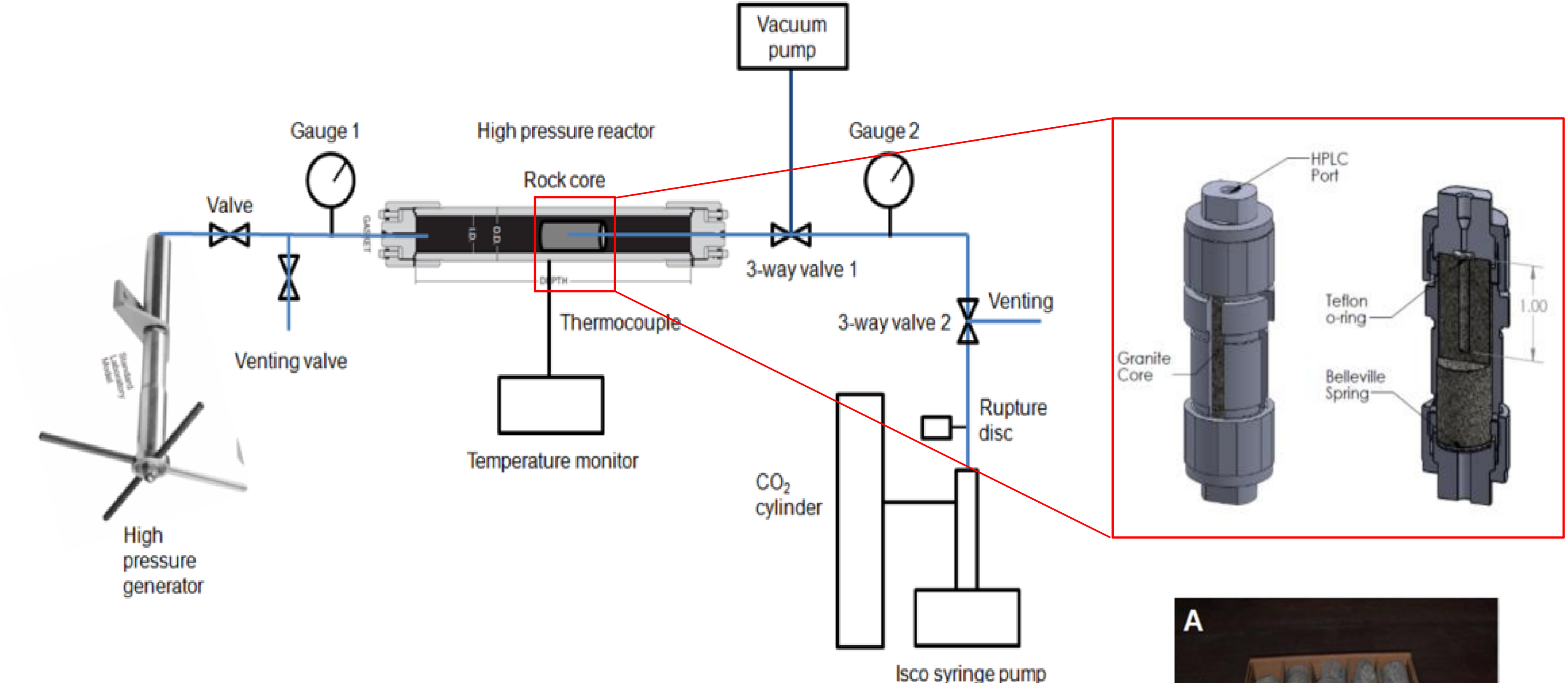
Stimulation System

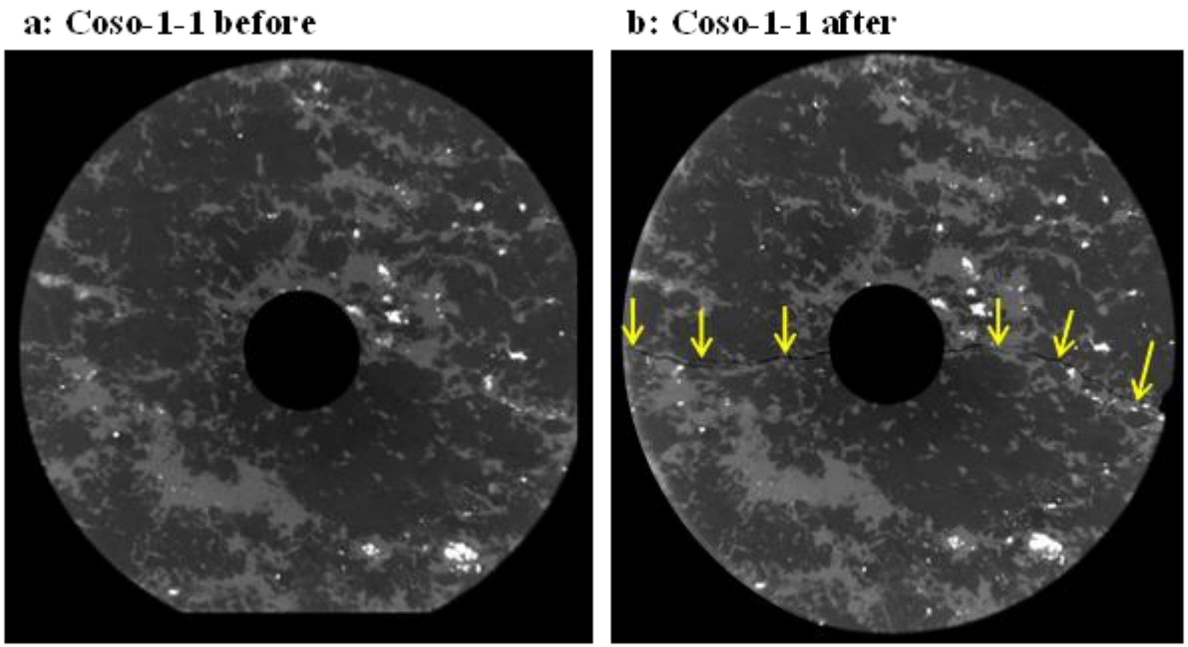


Working with geophysicists on experiment design

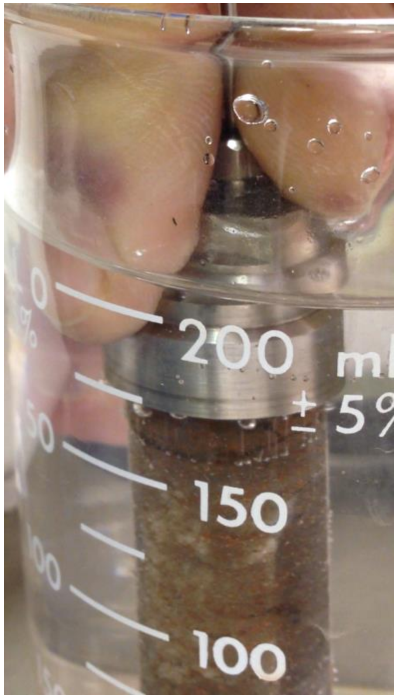
Right: Rock cores obtained from the Coso Geothermal site located in the eastern portion of central California, on the military-owned Naval Air Weapons Station at China Lake, the Coso Geothermal Field has been producing geothermal power continuously since 1987

Stimulation Studies

- <u>Confining P/T conditions</u>: 300 ºC and 333 atm; 1wt% PNNL fluid component
- pH= 3.5



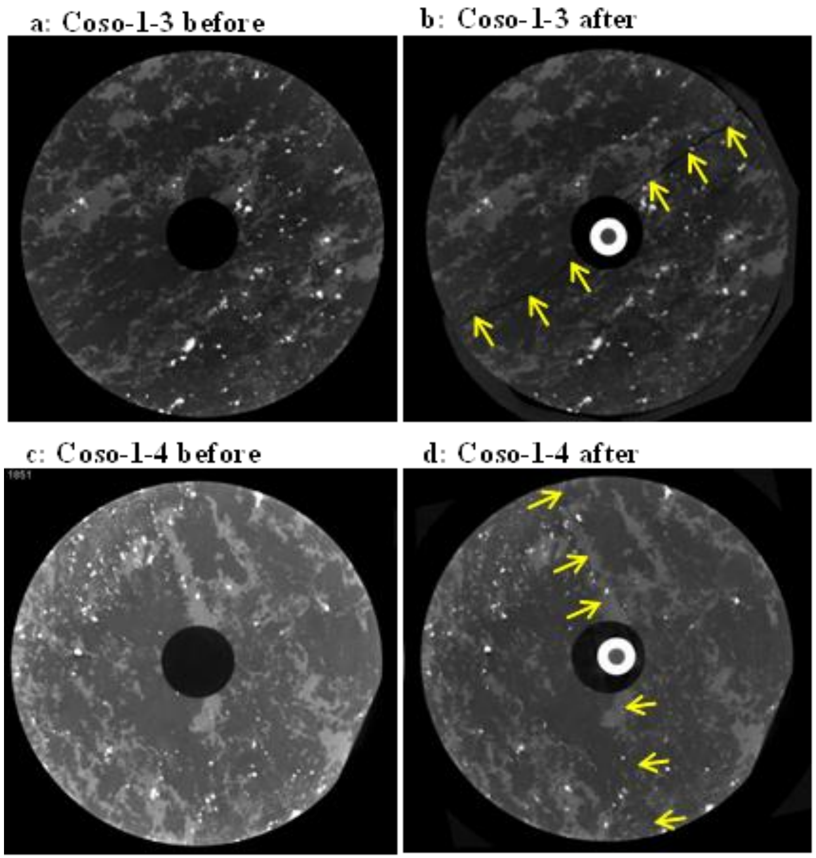
Coso 1-1: PNNL fluid
Effective P for fracturing= 17atm
Permeability= 8.8 mD



Coso 1-2, control experiment, <u>did not show</u> fracture creation/ propagation even at differential pressures of 170 atm

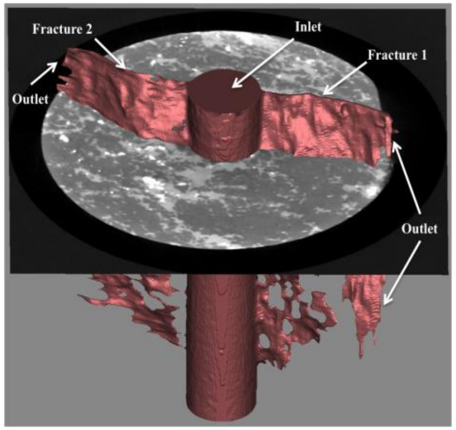
Stimulation Studies

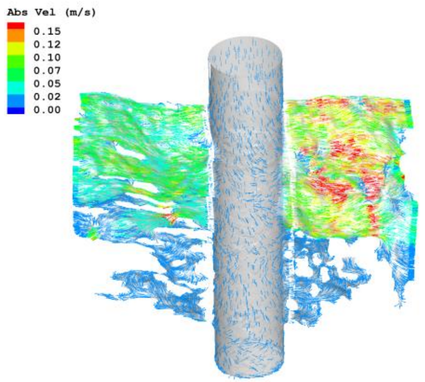
- <u>Confining P/T conditions</u>: 300 ºC and 333 atm; 1wt% PNNL fluid component
- pH= 7

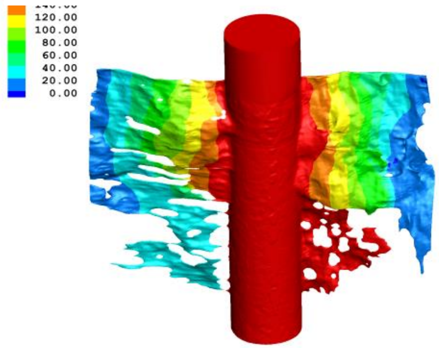


Coso 1-4: control exp.
Effective P for fracturing= 45 atm
Measured permeability= 0.6 mD

Coso 1-3: PNNL fluid
Effective P for fracturing= 27 atm
Measured permeability= 2.0 mD

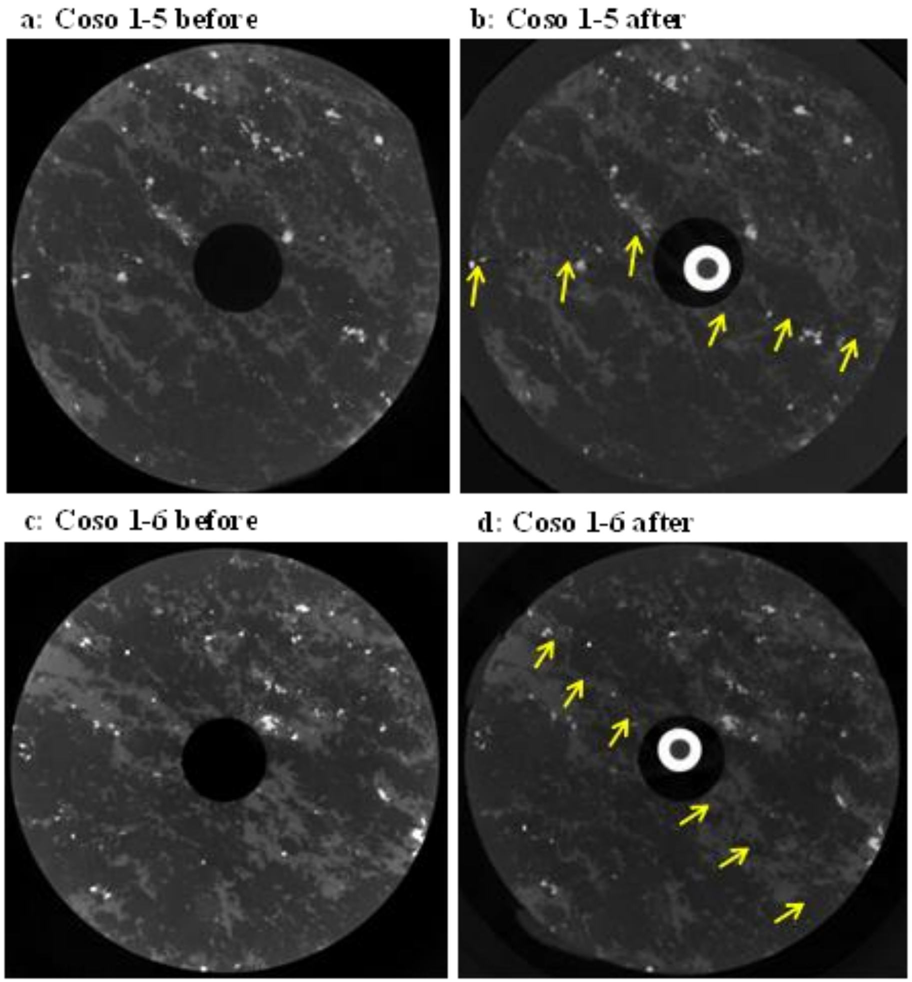






Stimulation Studies

- **<u>Confining P/T conditions</u>: 300 ºC and 333 atm; 1wt% PNNL fluid component**
- **pH= 10**



- **Coso 1-5: PNNL fluid**
- **Effective P for fracturing= 24 atm**
- **Measured permeability: 0.35 mD**

- **Coso 1-6: Control exp.**
- **Effective P for fracturing= 41 atm**
- **Measured permeability: 0.032 mD**

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Stimulation Studies

<u>Confining P/T conditions</u>: 300 ºC and 333 atm 1wt% PNNL fluid component

Exp. No.	Rock Sample	Temp. (°C)	Pressure (atm)	Fracking fluid	Effective pressure of rock fracking. (atm)	Permeability after fracturing exp. (mD)	Gas leaking test
1	Coso-1-1	300	333	PAA-CO_2	17	8.8	Yes
2	Coso-1-2	300	333	DIW/CO_2	>170 [a]	< 0.001 [b]	No [c]
3	Coso-1-3	300	333	PAA (pH7)-CO_2	27	2.0	Yes
4	Coso-1-4	300	333	pH 7 buffer-CO_2	45	0.60	Yes
5	Coso-1-5	300	333	PAA (pH10)-CO_2	24	0.35	Yes
6	Coso-1-6	300	333	pH10 buffer-CO_2	41	0.032	Yes

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Preliminary Economic Analysis

1) Reservoir stimulation represents approximately 45% ($3.3 million) of a typical well budget, which averaged $7.5 million (drilling plus completion, ~ 20 stages) in early 2011
2) PNNL fracturing fluid technology could be conservatively translated to a 50% reduction in the number of fracturing stages with smaller volumes of fracturing fluid applied.
3) Costs per well:

CO_2

A. 50 metric tons (assuming horizontal well of 3000 m at 300 C and 650 atm)
B. $4K ($80/ton CO_2)
C. $35K for handling and transportation

PNNL fluid component

A. 75 metric tons of PNNL fluid component (assuming 1 wt% and 4 million gallons of water used for stimulation)
B. $60K (assuming $0.80/Kg of PNNL component)

Total investment: $100K

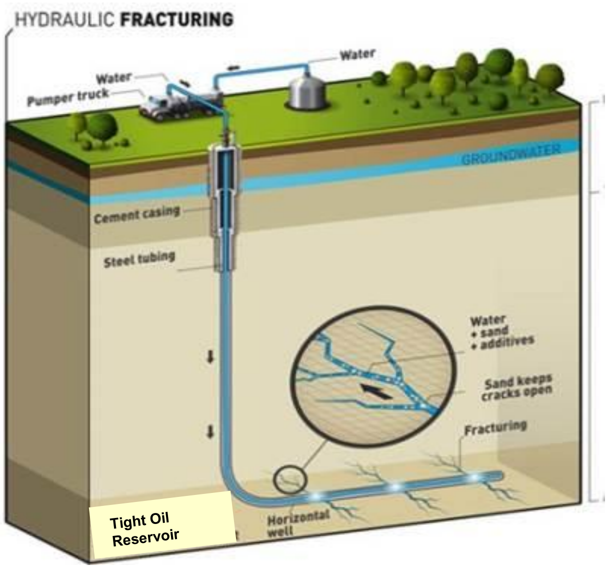
Total savings: $1.6M

Prospective for EGS and Tight Oil Recovery

1) Potential average savings are <u>$1.6 million</u> per well for reservoir stimulation as of 2011*

2) Create larger fractures with a less energy intensive process (effective pressures order of magnitude lower than current technology)

3) The amount of water required and waste water generated can be dramatically decreased.



4) <u>Flexible Technology</u>: PNNL fracturing fluid could be used in a range of reservoir P/T conditions and adapted to work at lower temperatures (different fluid component chemistries, CO_2 pressures and/or fluid component concentration)

5) Environmentally friendly and rheoreversible fluid (recyclable) will accelerate environmentally responsible and efficient domestic energy production.

6) PNNL fluid technology can optimize fracture permeability and stability focusing on maximizing oil flow rates due to predicted efficient fracture clean up

7) Key process infrastructure for CO_2 delivery is available.

Our Team

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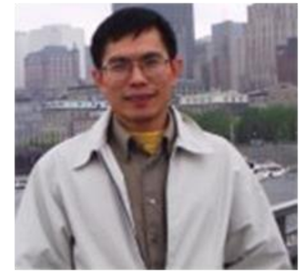

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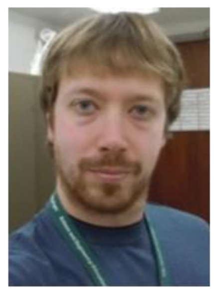

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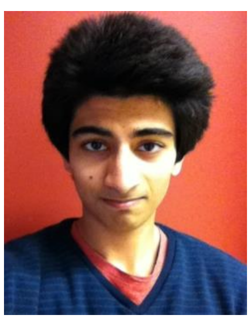

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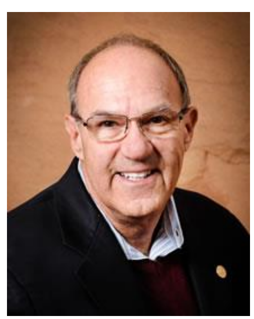

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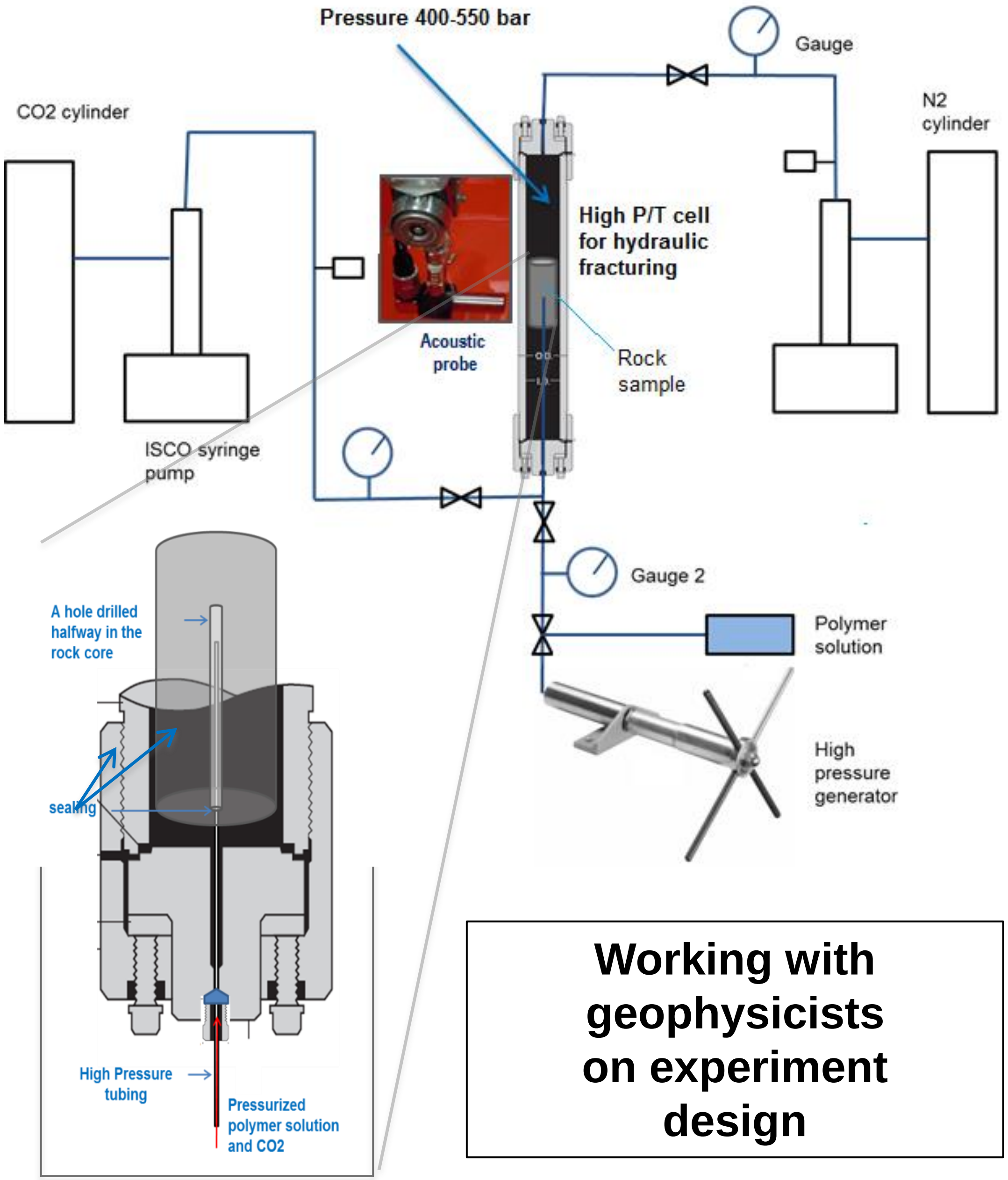
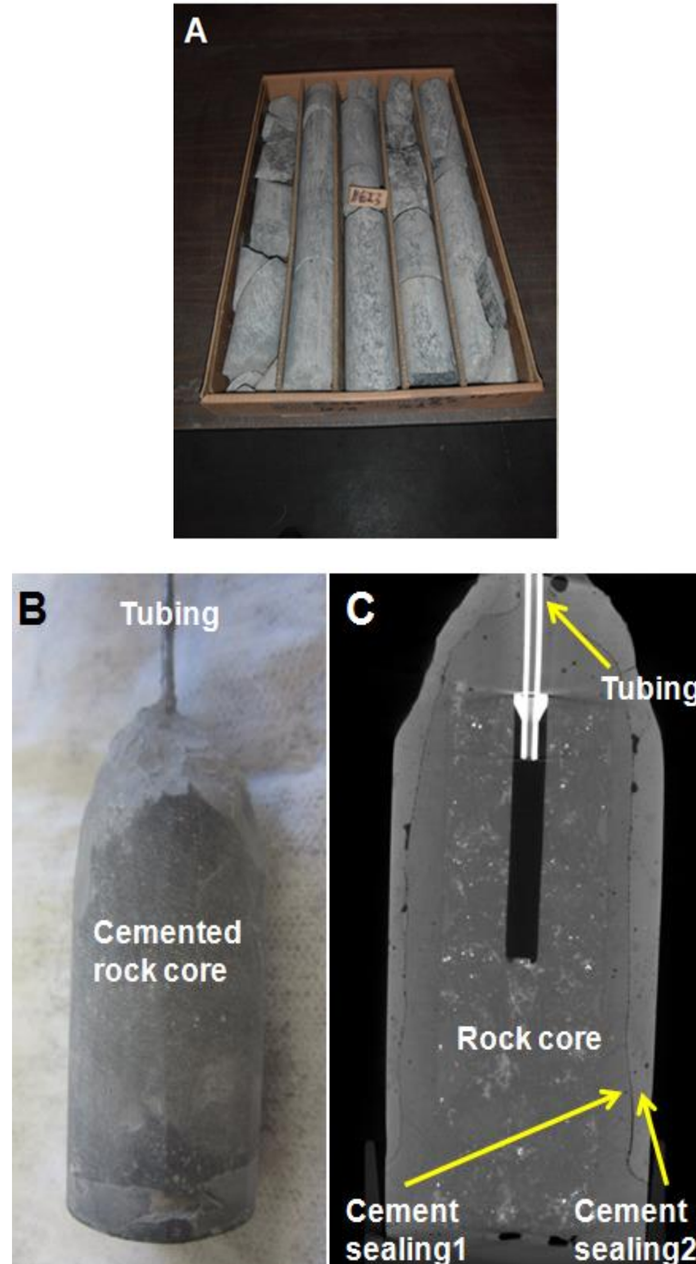
Thank you!

Backup Slides

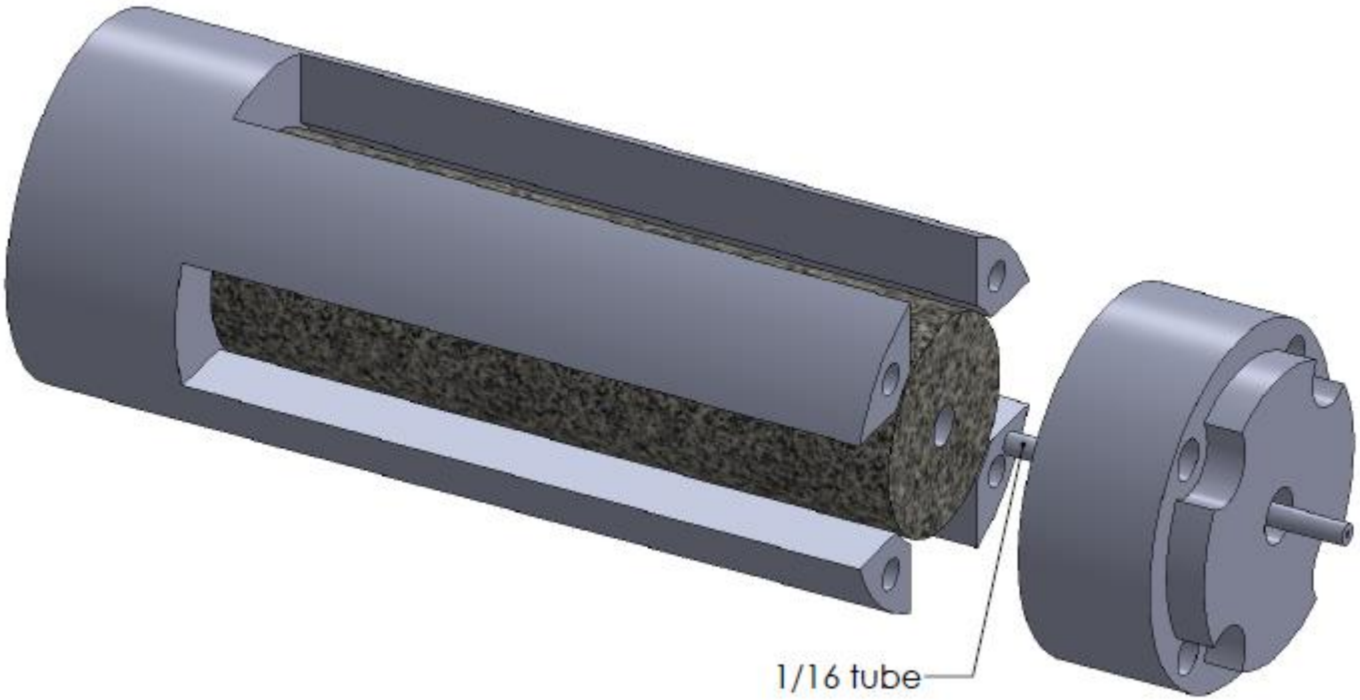
Stimulation System





Working with geophysicists on experiment design

Fracturing cradle



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